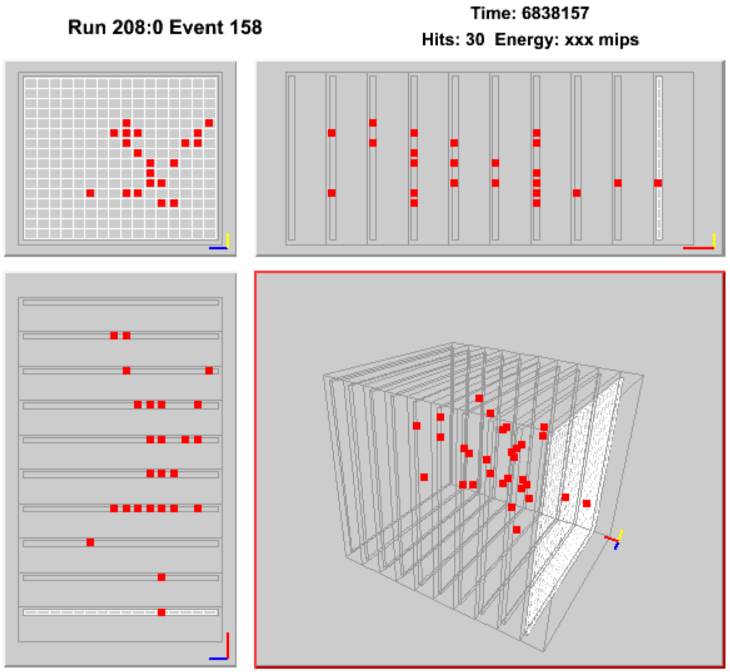
Tests of a Digital Hadron Calorimeter



José Repond
Argonne National Laboratory

CALICE Collaboration Meeting
March 10 – 12, 2010
University of Texas at Arlington

Outline

Monte Carlo Simulation = Integration of current knowledge of the experiment

Perfect knowledge → Perfect agreement with data
Missing knowledge → Not necessarily disagreement with data
Disagreement with data → Missing knowledge, misunderstanding of experiment
Perfect agreement with data → Not necessarily perfect knowledge

I Digital Hadron Calorimeter

Idea

Replace small number of towers with high resolution readout with large number of pads with single-bit (digital) readout

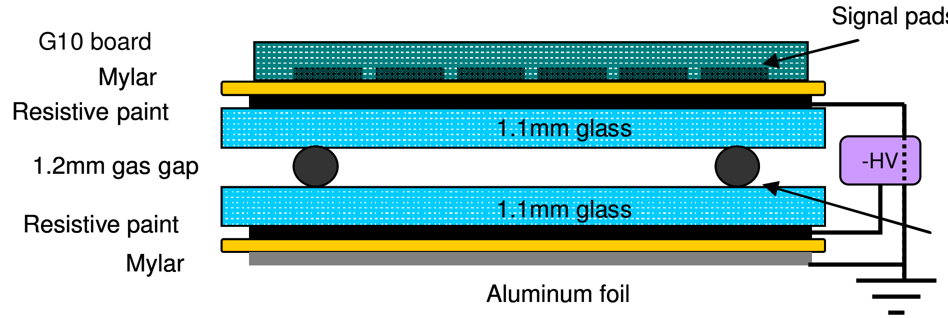
Energy of hadron shower reconstructed (to first order) as sum of pads above threshold

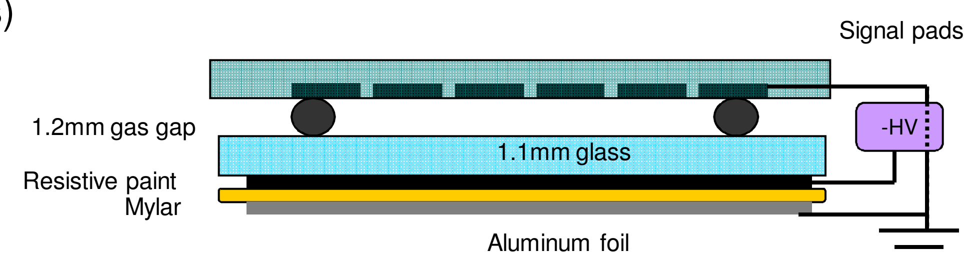
Concept provides high segmentation as required by the application of PFAs to jet reconstruction

Active element

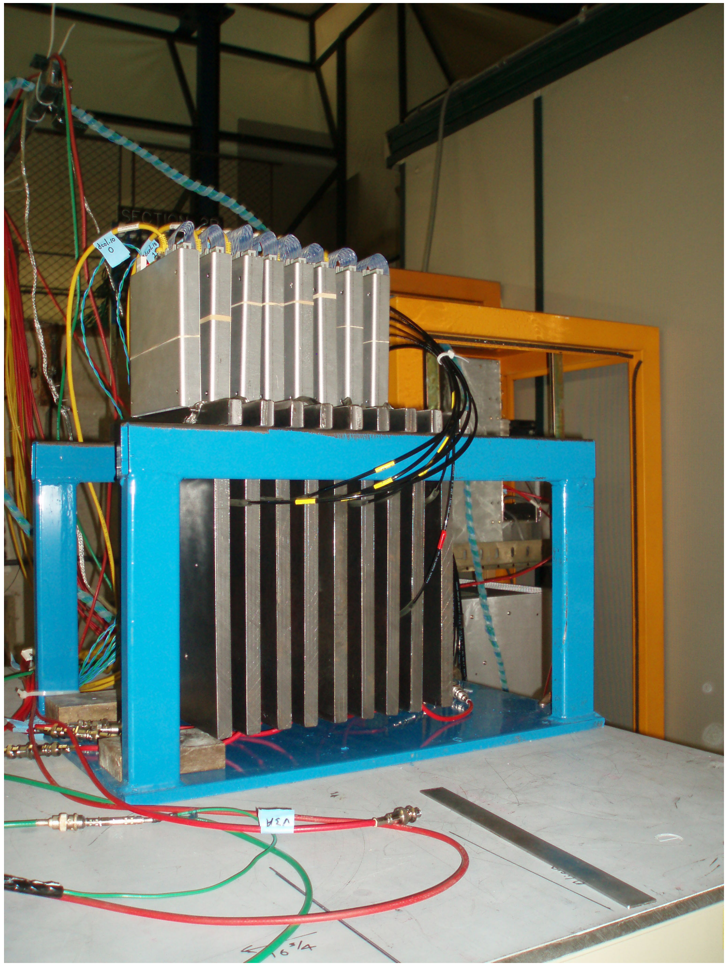
Resistive Plate Chambers

→ Simple in design
→ Cheap
→ Reliable (at least with glass as resistive plates)
→ Large electronic signals
→ Position information → segmented readout





II Vertical Slice Test



Small prototype calorimeter

Up to 10 RPCs, each 20 x 20 cm^2
1 x 1 cm^2 pad readout → up to 2560 channels

RPCs

Used up to 10 RPCs for muons
Only used RPC0 – RPC5 in analysis of e^+, π^+
Only used RPC0 for rate capability measurements

Absorber

Steel (16 mm) + Copper (4 mm)

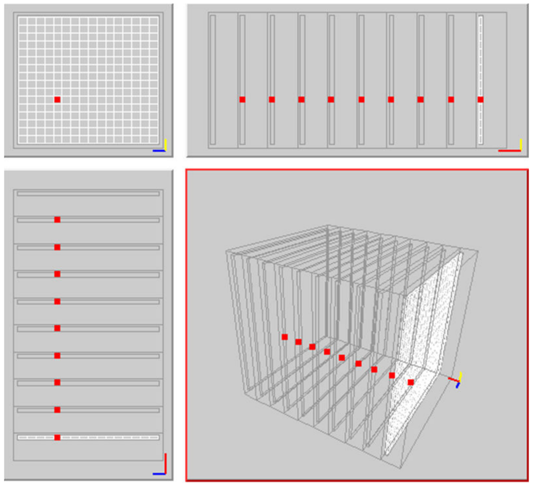
Test beam

Collected data in Fermilab's MT6 beam line
Used
- Primary beam (120 GeV protons) with beam blocker for muons
- Primary beam without beam blocker for rate measurements (varying intensity)
- Secondary beam for positrons and pions at 1,2,4,8, and 16 GeV/c

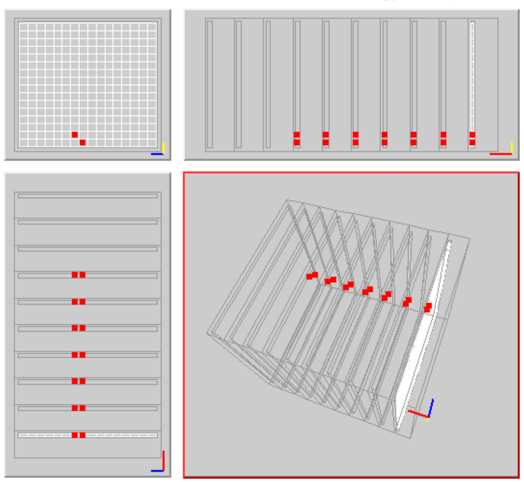
CALICE
Calorimeter for ILC

A few nice events from the testbeam….

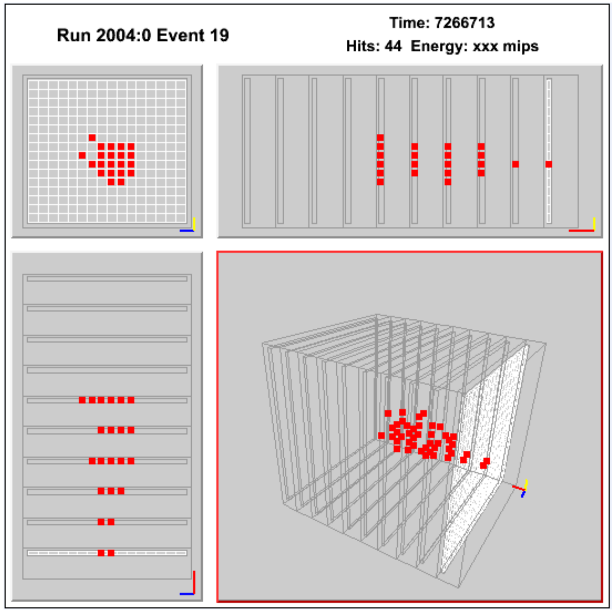
A perfect μ

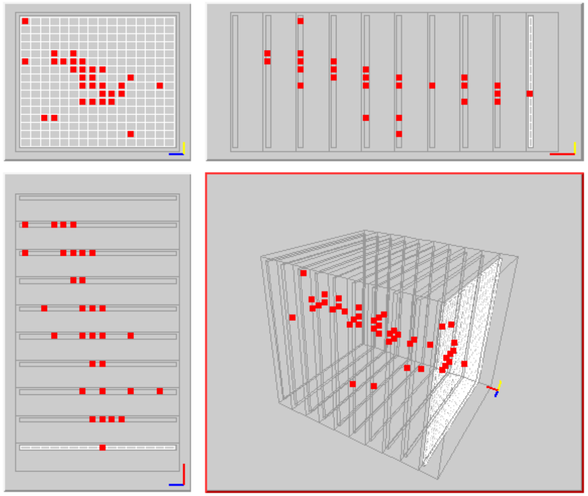


2 perfect μ's

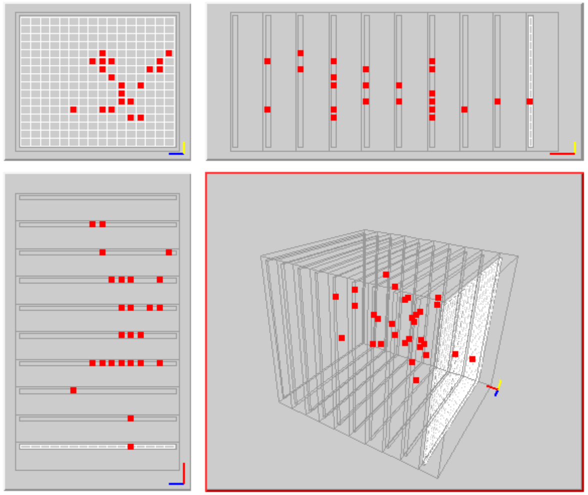


A e^+ shower

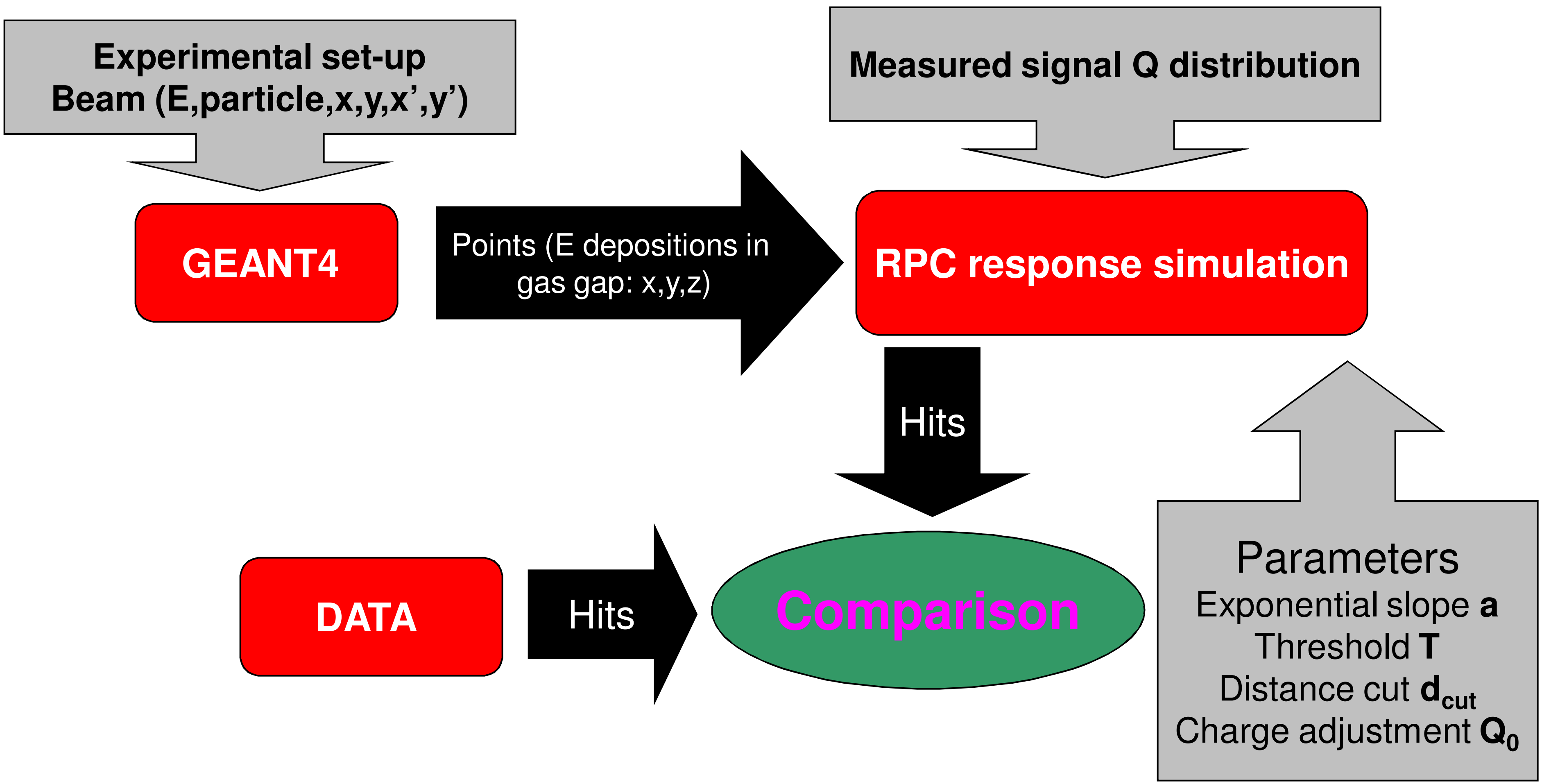




π^+ showers

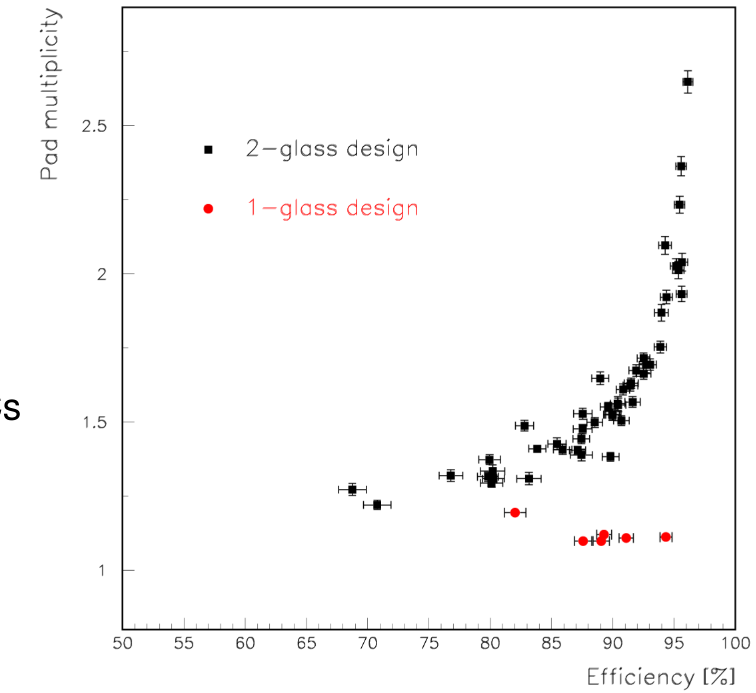


III Simulation Strategy



With muons – tune **a**, **T**, ($\mathbf{d_{cut}}$), and $\mathbf{Q_0}$
With positrons – tune $\mathbf{d_{cut}}$
Pions – no additional tuning

IV Simulating Muons



Broadband muons

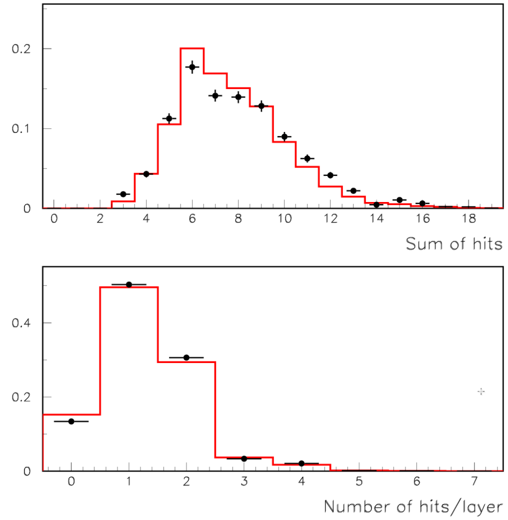
from primary 120 GerV protons (with 3 m Fe blocker)

Used to measure efficiency and pad multiplicity of RPCs
→ calibration constants

Tuned

slope **a**
threshold **T**
charge adjustment $\mathbf{Q_0}$

→ reproduce the distributions of the sum of hits and hits/layer



Data

Monte Carlo simulations
after tuning

Published as B.Bilki et al., 2008 JINST 3 P05001
Published as B.Bilki et al., 2009 JINST 4 P04006

V Simulating Positrons Showers

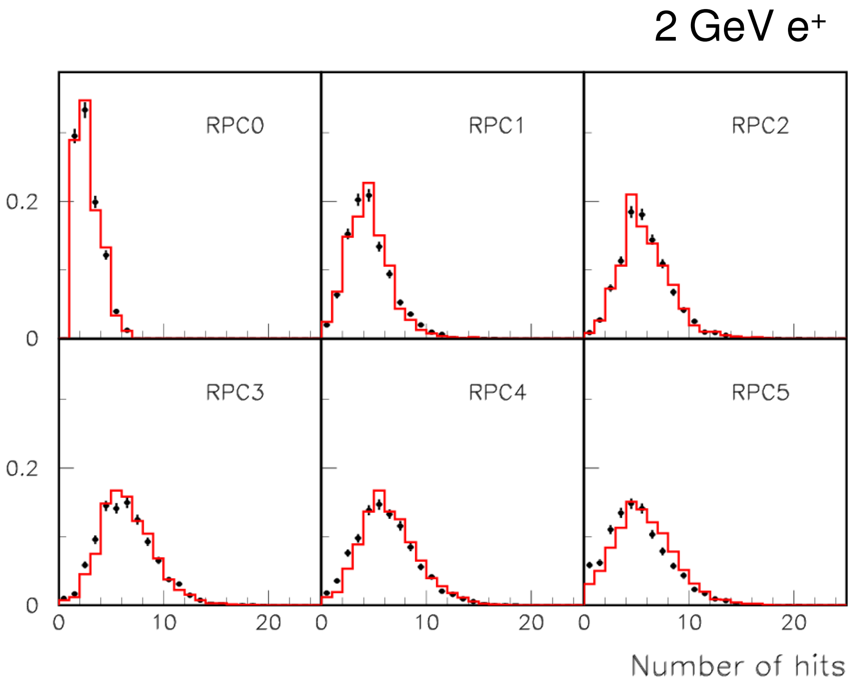
Positrons at 1, 2, 4, 8, 16, GeV

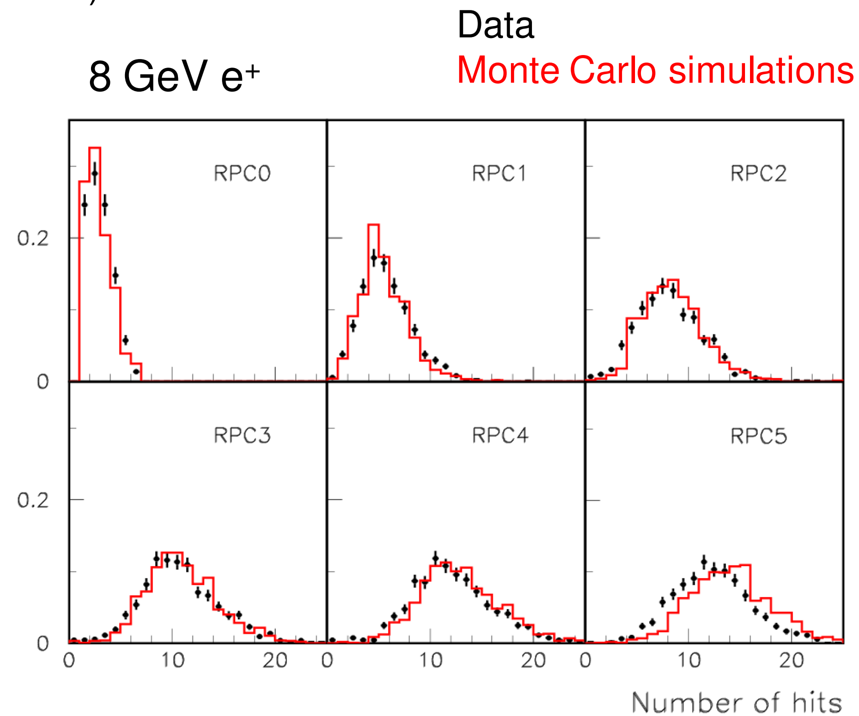
from FNAL testbeam (with Čerenkov requirement)

Tuned

distance cut $\mathbf{d_{cut}}$

→ reproduce distributions in individual layers (8 GeV data)



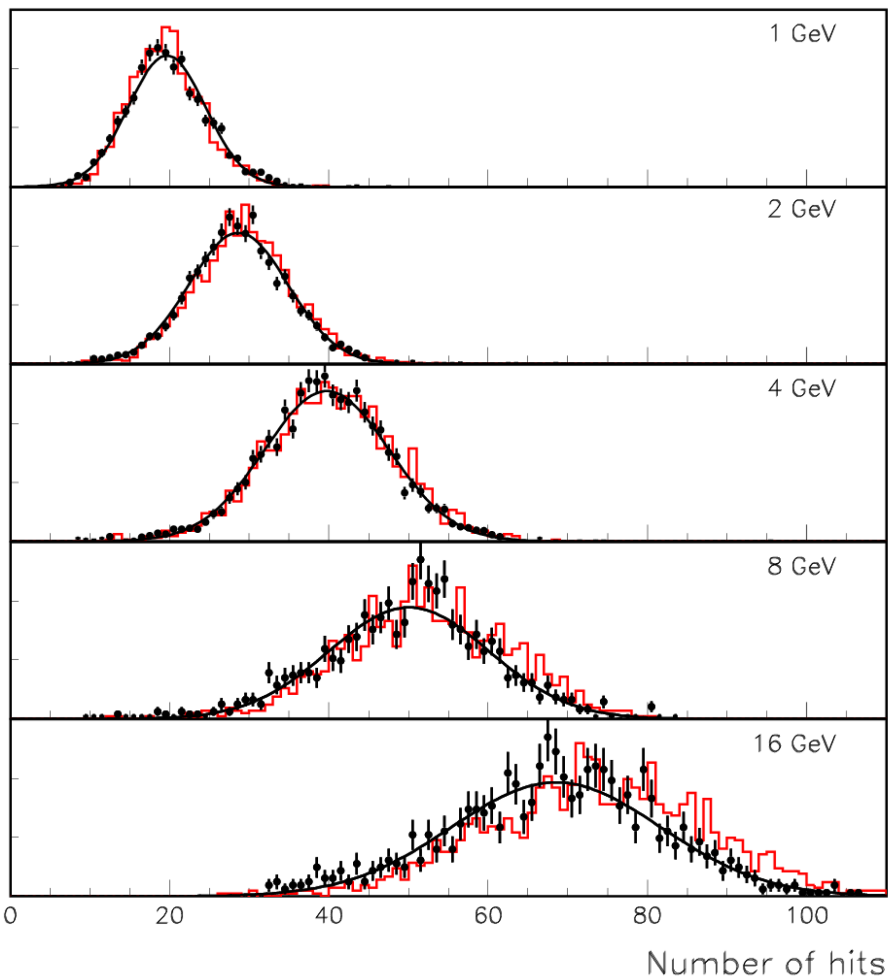


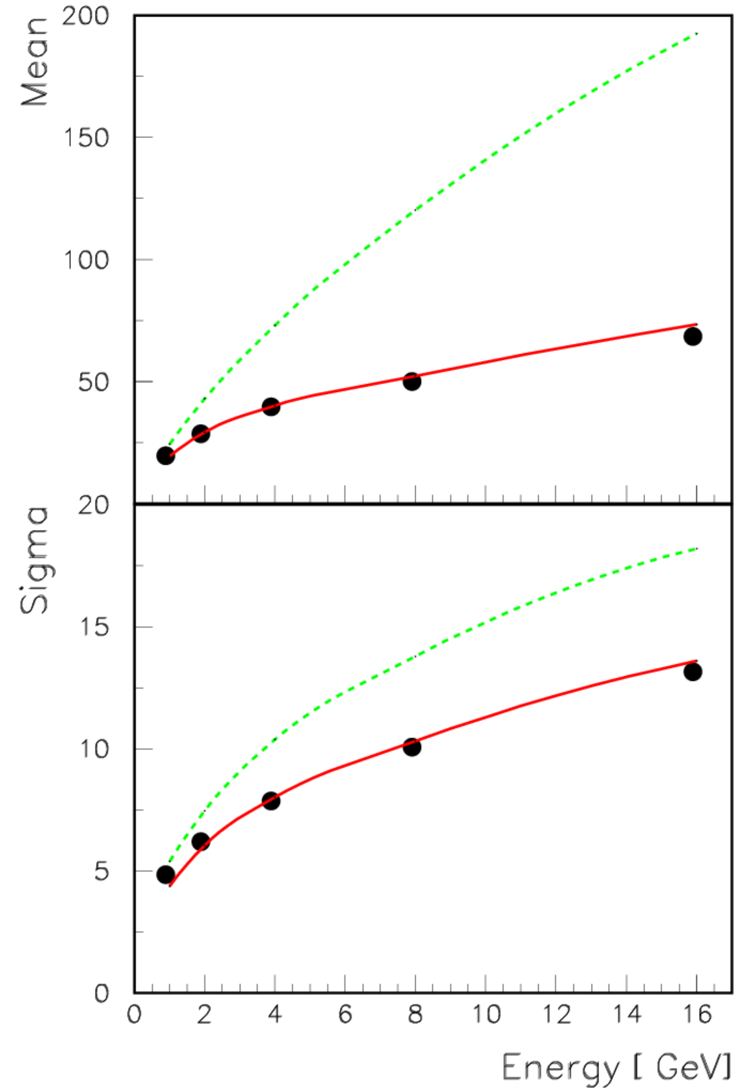
Published as B.Bilki et al., 2009 JINST 4 P04006

Data

Monte Carlo simulations – 6 layers

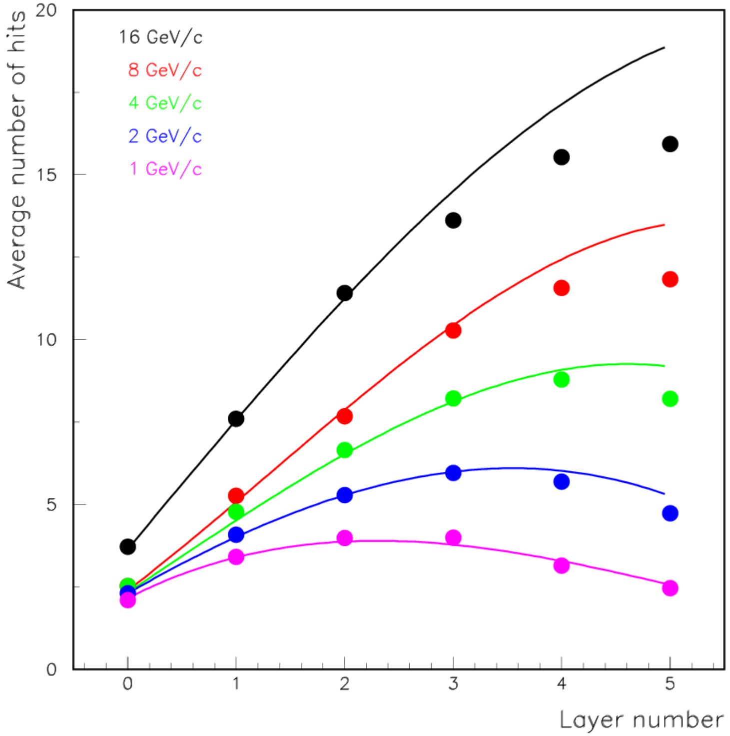
Monte Carlo simulations – Infinite stack



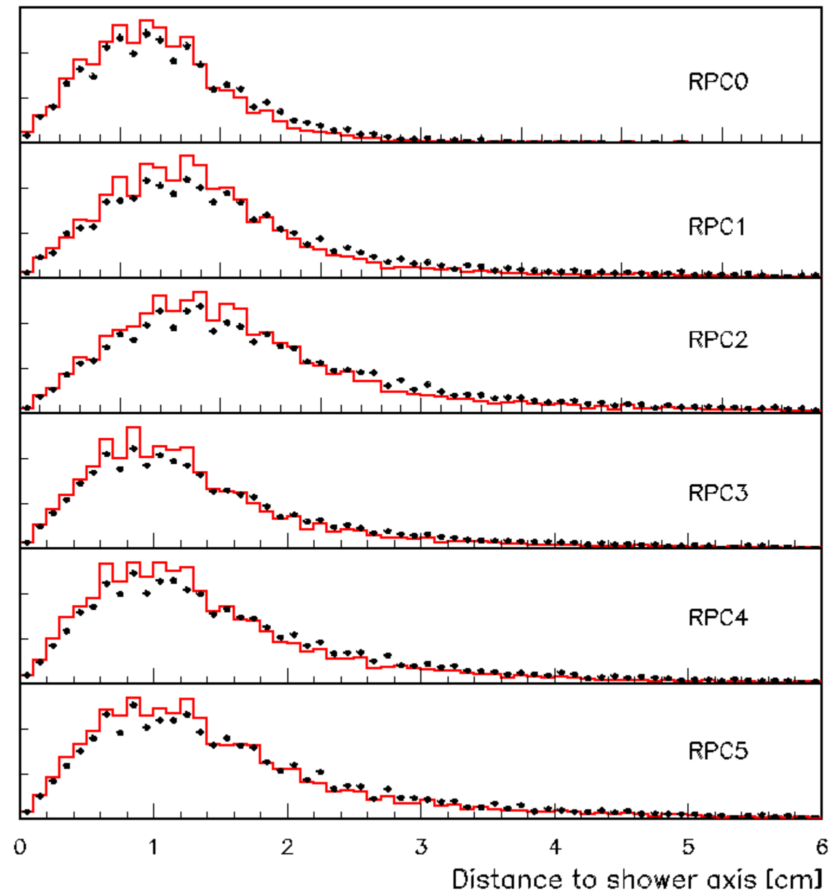


Remember: this is a hadron calorimeter

Longitudinal shower shape



Lateral shower shape for 2GeV e^+



Effects of high rates seen

Charged particle rate ~ 100 Hz/cm^2

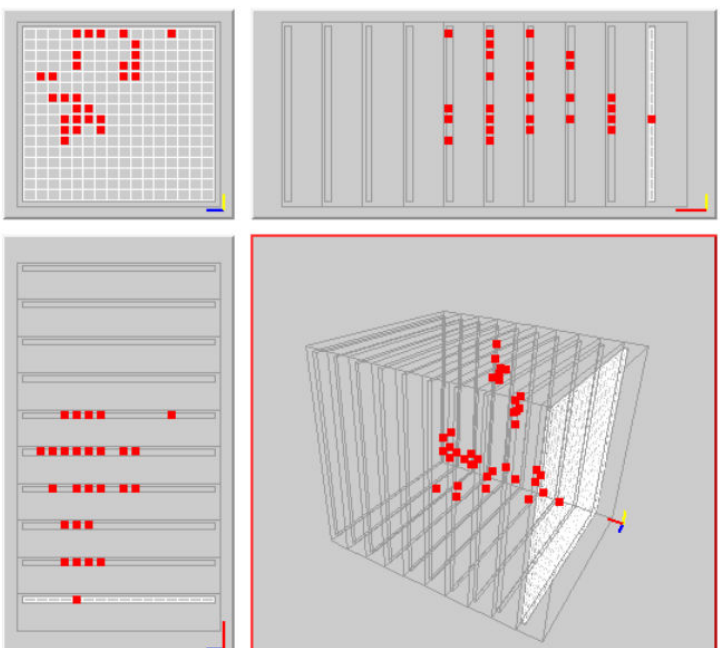
But did not take into account significant flux of photons in beam line

VI Simulating Pion Showers

Momentum [GeV/c]	Stack of iron bricks	Number of events	Beam intensity [Hz]	Fraction of events without veto from the Čerenkov counters[%]
1	No	1378	547	6.0
2	No	5642	273	5.9
	Yes	1068	80	57.3
4	No	5941	294	15.5
8	No	30657	230	24.6
16	No	29889	262	28.0

Trigger =

Coincidence of 2 scintillator paddels + veto from either Čerenkov counter

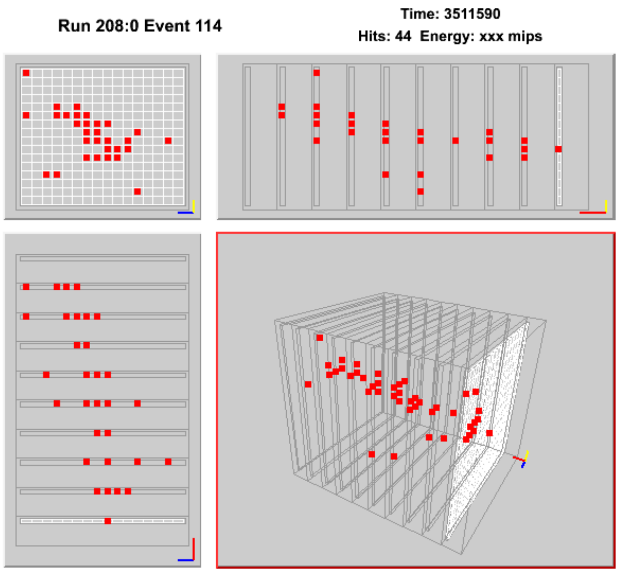


6 layer stack corresponding to 0.7 λ_I

Published as B.Bilki et al., JINST 4 P10008

Event Selection

Requirement		Effect
At least 3 layers with hits		Rejects spurious triggers
Exactly 1 cluster in the first layer		Removed upstream showers, multiple particles
No more than 4 hits in first layer		Removed upstream showers
Fiducial cut away from edges of readout		Better lateral containment
Second layer	At most 4 hits	**MIP selection**
	At least 5 hits	**Shower selection**



Brick data

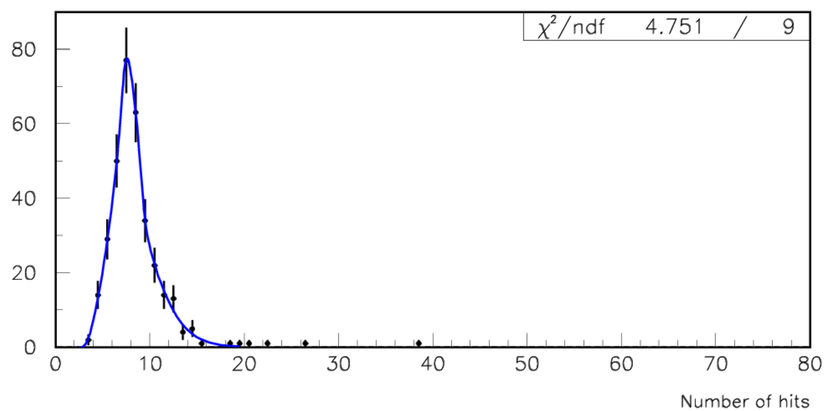
Calibration close to expected values
→ no corrections applied

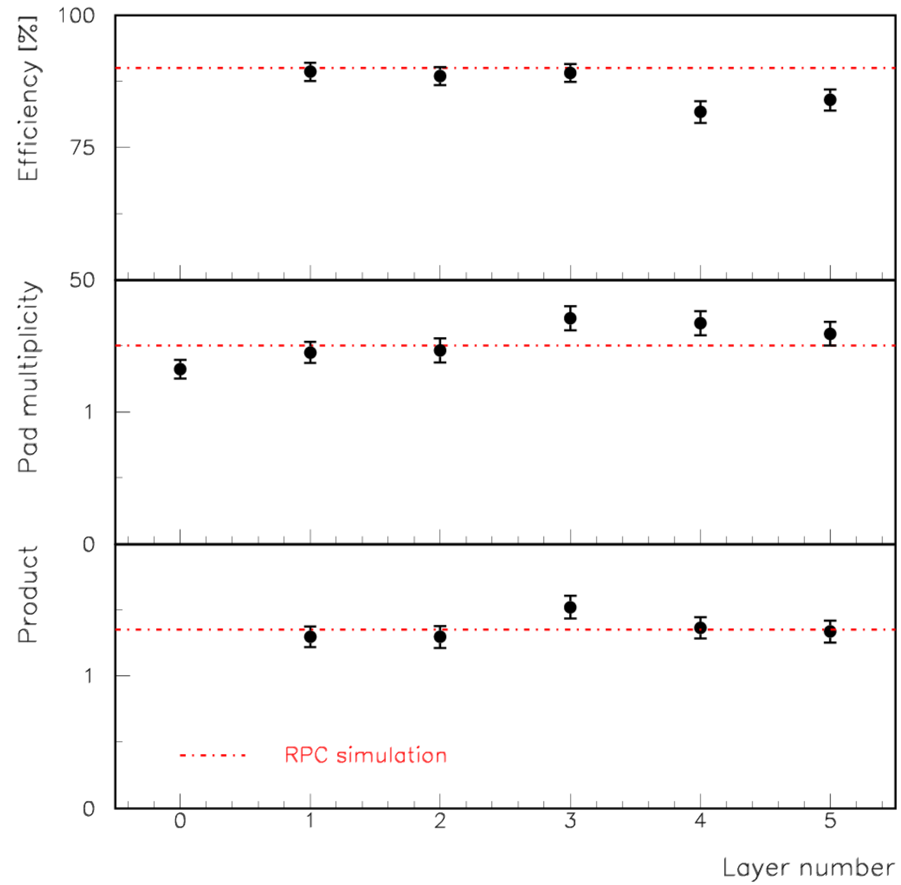
Secondary beam with +2 GeV/c selection

Fe blocks in front of RPCs

~ 50 cm deep corresponding to 3 λ_I
→ 97% of π interact
→ ΔE_μ ~ 600 MeV

Sum of hits in the DHCAL (RPC0 – RPC5)



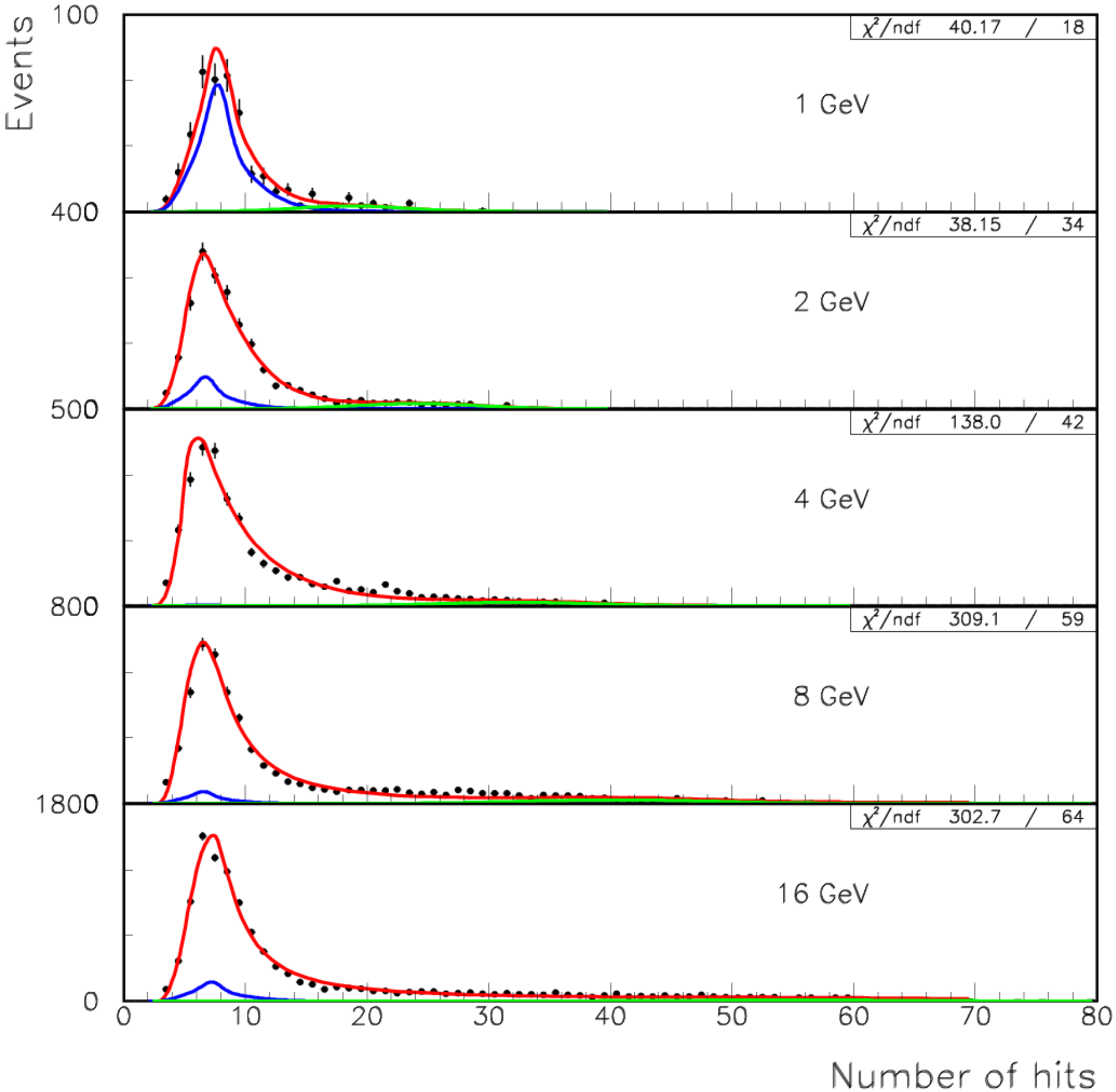


→ Emperically fit to

$$\mathbf{y} = \alpha \mathbf{e}^{-\frac{1}{2}(\frac{\mathbf{x}-\beta}{\gamma})^2} + \delta(\mathbf{x}-\mathbf{x}_0)^\epsilon \mathbf{e}^{\phi(\mathbf{x}_0-\mathbf{x})}$$

In the following this will be our μ signal shape

MIP Selection



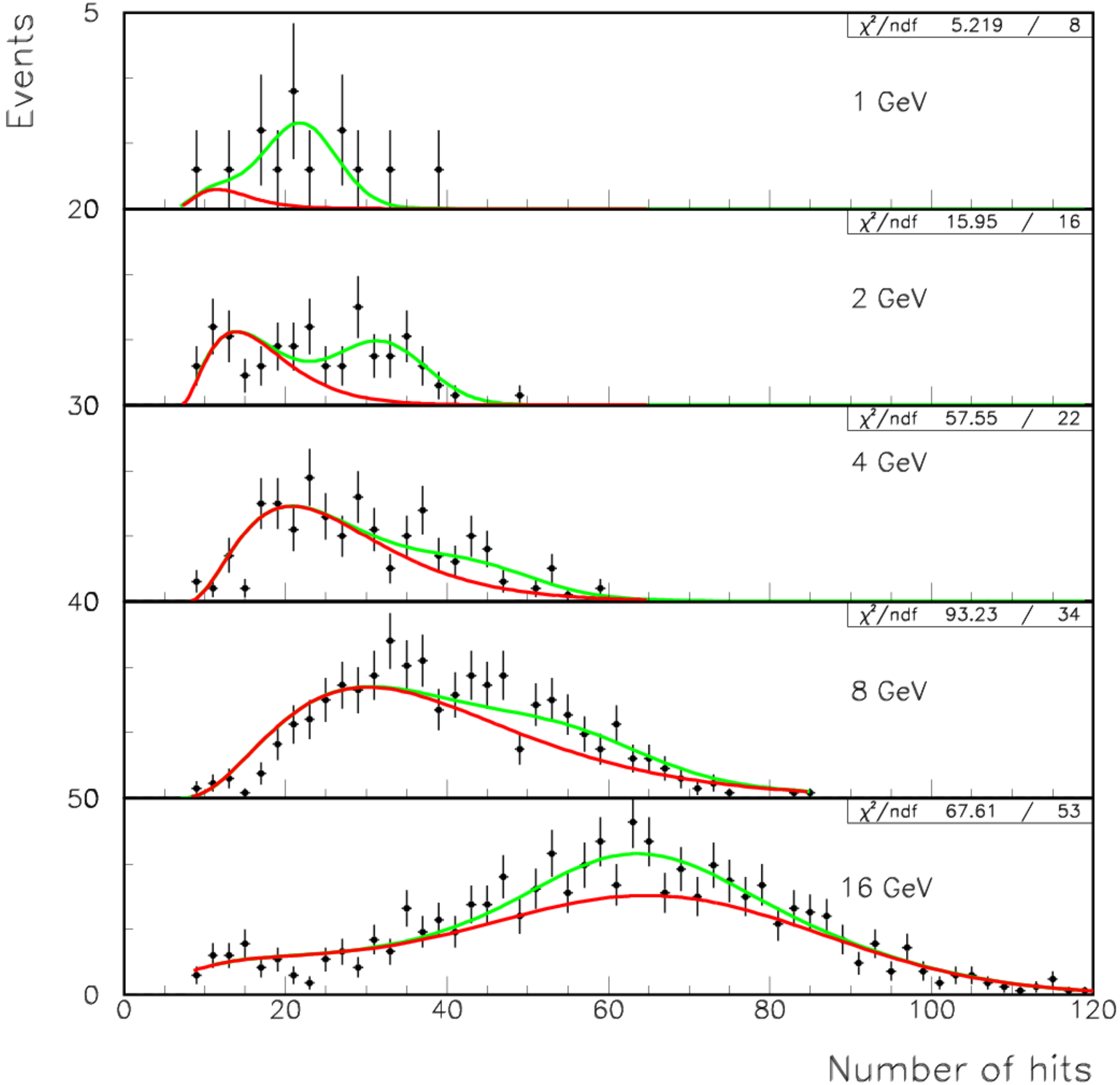
Fit to 3 components

- **Muons** (from brick data)
- **Pions** (from MC, not shown)
- **Positrons** (from MC)

(red line sum of 3 components)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate)

Shower Selection



Fit to 2 components

- Pions (from MC)
- Positrons (from MC)

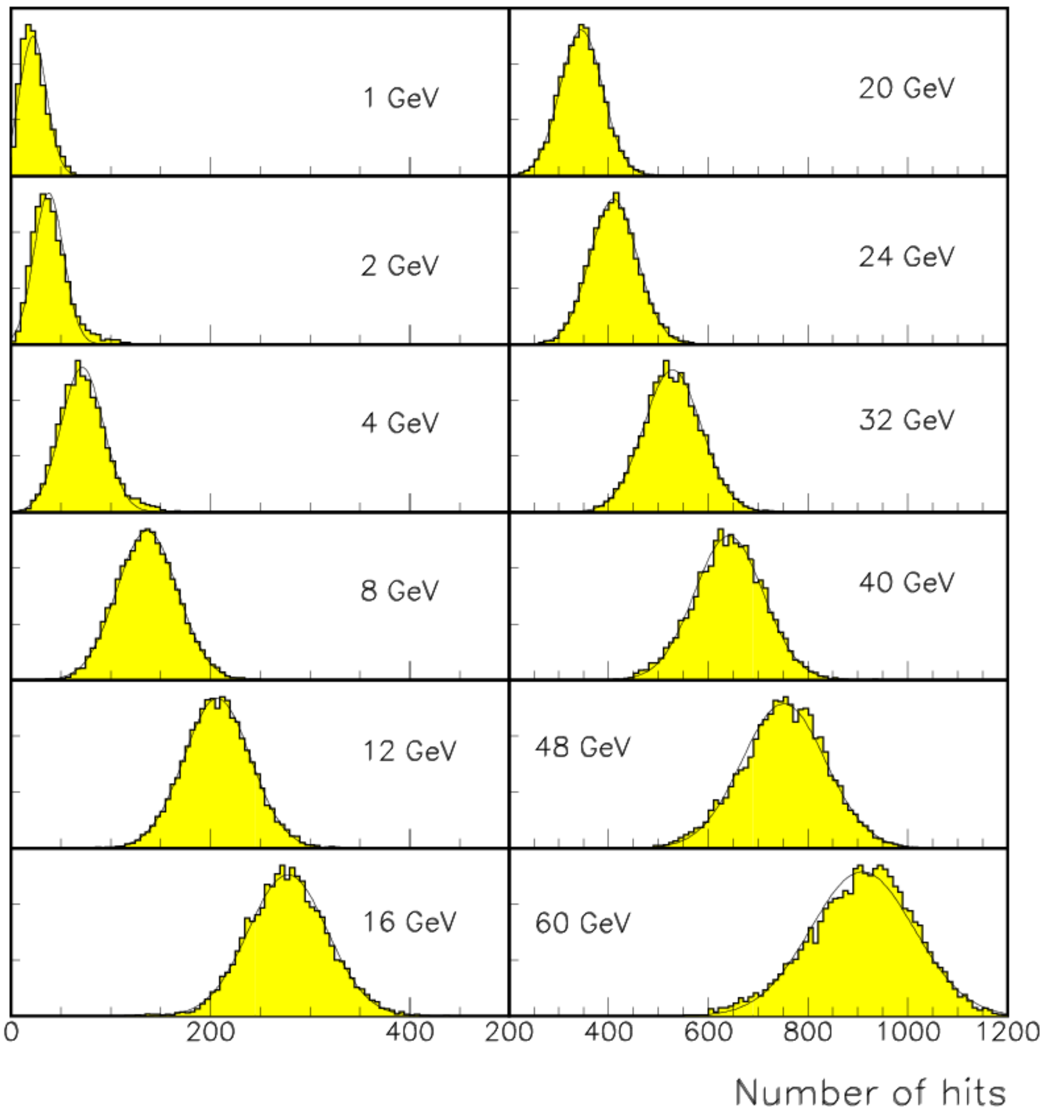
MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate) at 16 GeV (-9%)

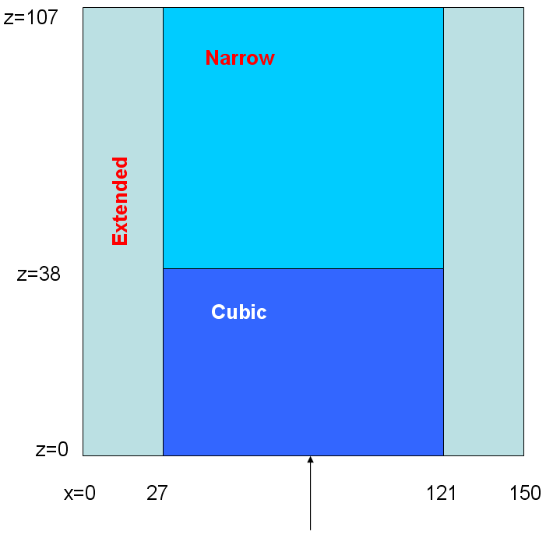
Reasonable description by simulation

Positron contamination at low energies

Not many pions at low energies

VII Studies of Larger Systems

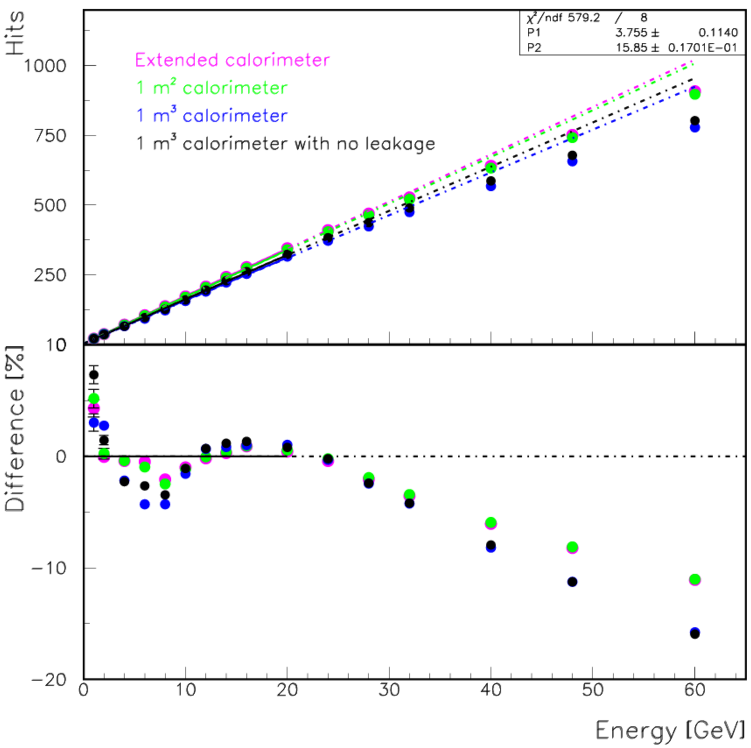


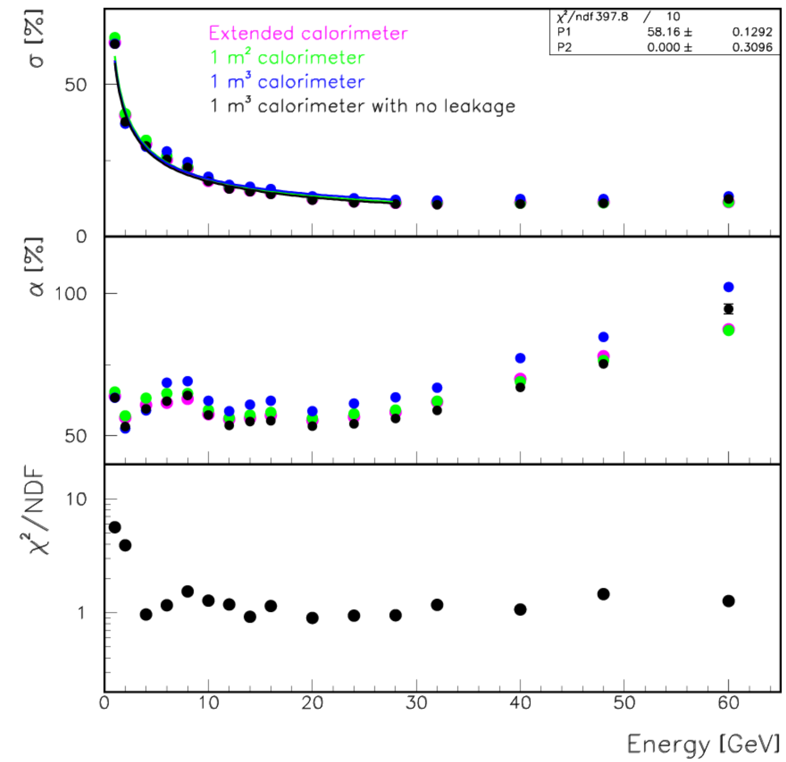


107 layers (minimal leakage)
Each 1.5 x 1.5 m^2

RPC performance as
for Vertical Slice Test

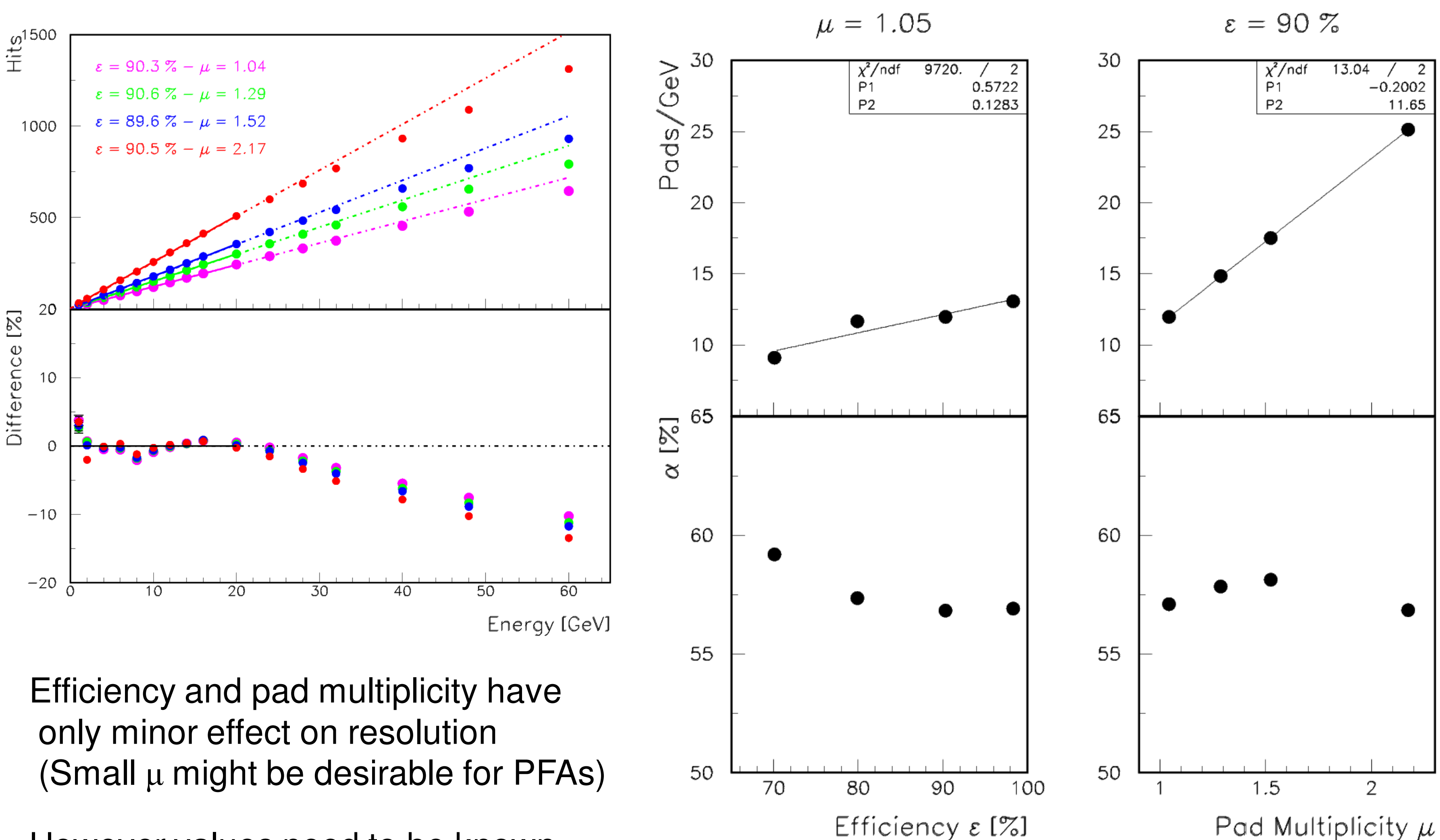
Reasonable Gaussian fits for E > 2 GeV





Reasonable Gaussian fits for E > 2 GeV
Discontinuity at E ~ 8 GeV (surprising, changes with physics list)
Non-linearity above E ~ 20 GeV (saturation)
Resolution ~ 58%/√E(GeV) (for E < 28 GeV)
Resolution degrades above 28 GeV (saturation)
Resolution of 1m^3 with containment cut somewhat better than for extended calorimeter

Study of different extended RPC-based calorimeters

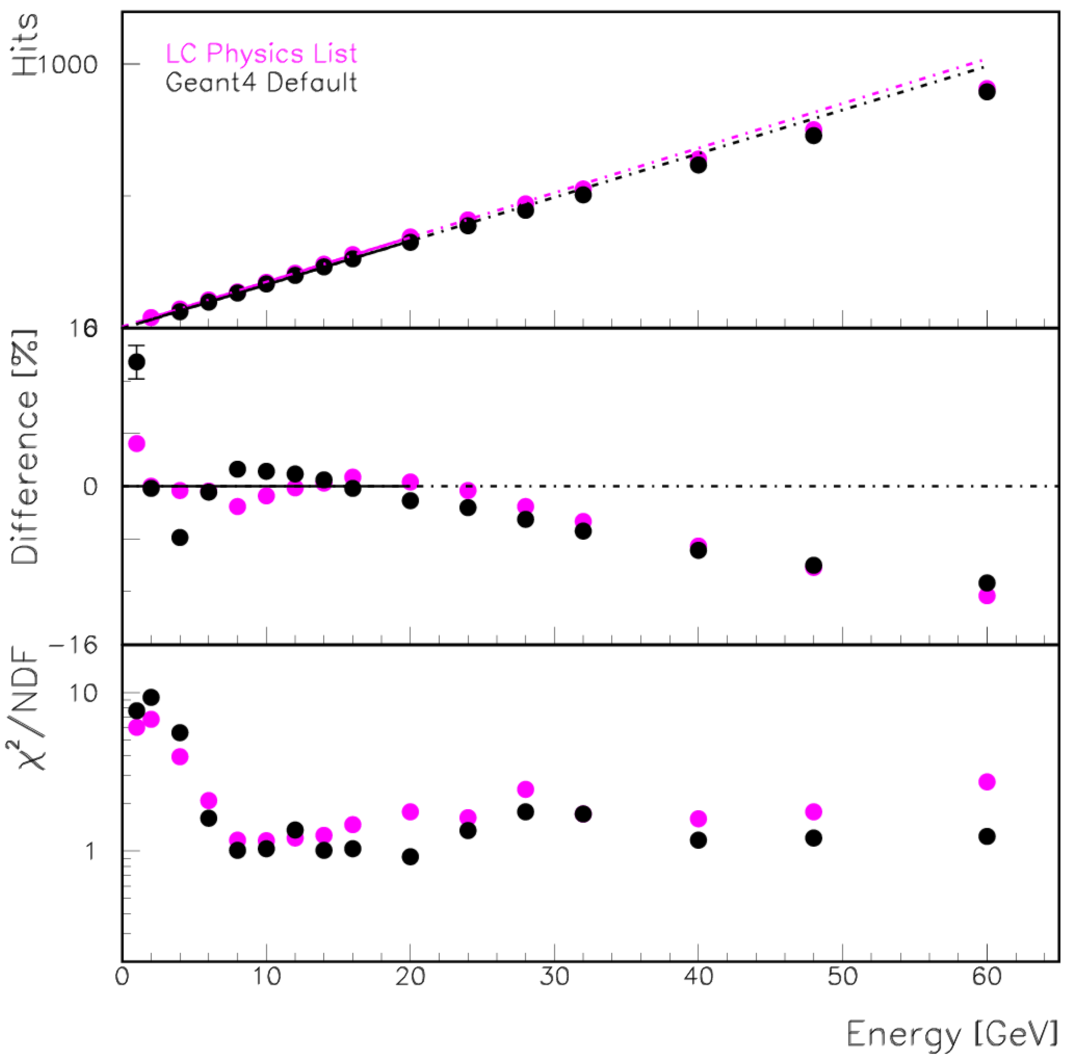


Efficiency and pad multiplicity have only minor effect on resolution (Small μ might be desirable for PFAs)

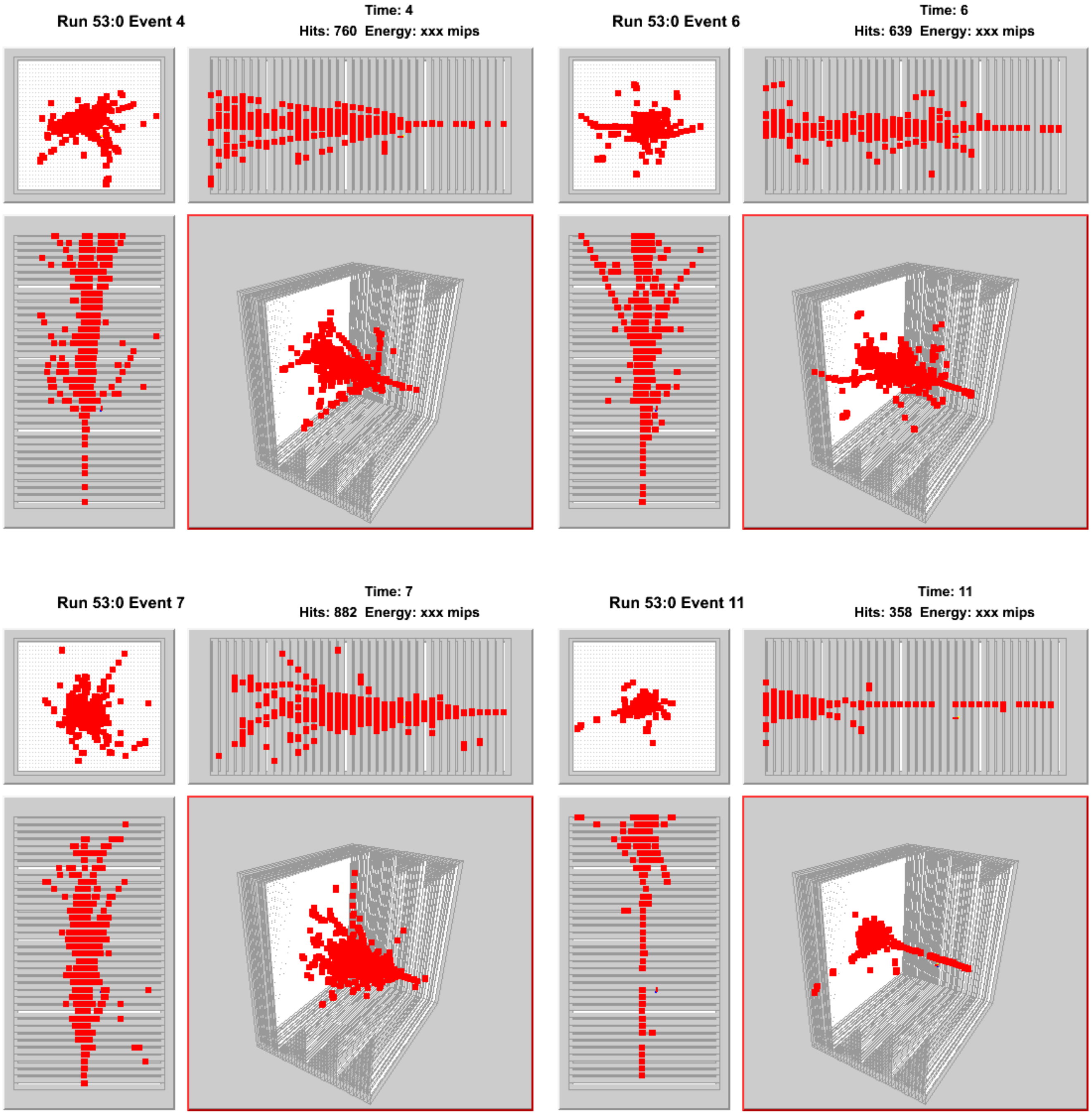
However values need to be known

Linear calibration corrections for ε,μ will work (P_1 ~ 0)

Study with different physics lists



Discontinuity seems
to move from 8 to 4 GeV



60 GeV Pions

GEANT4 simulation +
RPC response simulation

VIII Conclusions

A small scale prototype **Digital Hadron Calorimeter** was built

Contained up to 10 layers with a maximum of 2560 readout channels

The prototype was tested in the **Fermilab test beam**

Broadband muons, protons at 120 GeV (with vayring intensity), pions and positrons with 1 – 16 GeV/c

The **rate capability** was established

Loss of efficiency for rates > 100 Hz/cm^2
Analytical calculations reproduce measurements

The **efficiency and pad multiplicity** for single tracks

Measured with broad band muons as function of HV and threshold

Simulation of the response of the calorimeter with

GEANT4 and a standalone program simulating the RPC response

Response to **positrons and pions** with 1 – 16 GeV

Measured and compared to simulation (adequate agreement apart from residual rate effects)

Simulation of **larger system**

Digital hadron calorimetry is predicted to work (58%/$\sqrt{E}$)

Publications

Our environmental paper was published on February 24, 2010 as

Q.Zhang et al., 2010 JINST 5 P02007

This was our 6th refereed paper, the 5th based on the Vertical Slice Test

This completed the analysis of the Vertical Slice Data